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Low-Cost
Solar Array Project

DOE/JPL-1012-52
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LSA Field Test Annual Report August 1979-August 1980

Peter Jaffe

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Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 81-12)

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ABSTRACT

After almost four years of endurance testing of photovoltaic modules, no fundamental life-limiting mechanisms have been identified that could prevent the twenty-year life goal from being met. The endurance data show a continual decline in the failure rate with each new large-scale procurement. Cracked cells and broken interconnects continue to be the principal causes of failure. Although the modules are more adversely affected physically by hot, humid environments than by cool or dry environments, there are insufficient data to correlate failures with environment. There is little connection between the outward physical condition of a module and changes in its electrical performance. Electrical degradation is a transient condition that is generally intermittent and is present before a module destined to fail finally fails. Analysis of year-long electrical performance data indicates that the fill factor is insensitive to most measurement problems and remains the best diagnostic tool for determining module degradation. Investigations at the JPL site reveal that shadowing the indirect component of irradiance can reduce the electrical output of modules and result in anomalous performance data. Extrapolating this result to arrays suggests that a loss of power can result if indirect shadowing is not considered in the array layout. The introduction of the Portable I-V Data Logger was a success. About 1200 high quality I-V curves were obtained during a tour of the 15 remote sites. Next year a major reorganization in the inventory of test modules is planned. A significant portion of the older modules will be removed and replaced with modules from the upcoming Block IV large-scale procurement.

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SECTION I

INTRODUCTION

This report summarizes field testing activities for the period September 1, 1979 to August 31, 1980, the third full year of operation. The organization of the report parallels the different field test functions.

Section II reviews the operations of the 16 test sites comprising the test network. Section III discusses progress made in the area of data acquisition techniques and instrumentation development, including a discussion of data accuracy and the new Portable I-V Data Logger. Section IV summarizes the endurance test data obtained from the modules deployed at the test sites. Section V discusses future plans, including plans for enlarging the test sites. Also detailed in Section V is a change in emphasis at the JPL site.

SECTION II

TEST SITE OPERATIONS

Changes to the 16 site network were minimal last year; no new modules were deployed and no changes were made to the physical layouts of the sites. Table 2-1 contains a summary of the key features of the sites and Table 2-2 contains a representative summary of yearly weather highlights (1978). Figures 2-1 to 2-3 contain front- and rear-view photographs of the principal test modules, and Table 2-3 contains a description of the key features of these modules. Specific information about changes and noteworthy activities at the sites is presented below.

A. JPL SITE

The acquisition of three new pieces of equipment greatly improved the data system. A 75-inch-per-second, 9-track Cypher magnetic tape unit increases the data archiving capability and improves the overall flexibility of the data acquisition system. A 200-channel DORIC satellite provides increased capacity in handling thermocouple and millivolt inputs. A General Eastern automatic dew-point and ambient air temperature measurement unit upgrades the humidity and air temperature data. The addition of the magnetic tape unit made possible several planned data management changes. The I-V archiving schedule was changed from one set per week to daily. The collection intervals for weather data were changed from every 15 minutes to every 5 minutes. Weather and insolation data previously available only in hard copy form now will be stored on tape as well.

With the objective of automating the screening and analysis of module data, additions were made to the data system software. A new daily summary task, SUMAR5, was written. SUMAR5 provides a hard-copy listing of potentially bad modules, defined as modules whose fill factors deviated by more than 3 percent from their nondegraded condition. This program has been extremely useful in reducing the large quantity of data obtained daily and in focusing on potentially bad modules. SUMAR5 also creates a file containing the change in short-circuit current and peak power of the nondegraded modules, and the insolation values obtained during data collection. This file supplies the basic information that will be used in the next generation of analysis programs, which is currently being planned and should be implemented in 1981.

During the past few years many groups other than the Field Test Group have also found the JPL site to be a good place to perform their experiments. Several studies are currently being carried out by other groups:

Organization	Purpose of Study
LSA Encapsulation Task	Develop instrumentation to detect and monitor several environmental parameters (pH, rain, moisture, etc.)
LSA Encapsulation Task	Obtain information on dust collection characteristics of various module surfaces at elevated voltages, up to 1500 volts.

Table 2-1. Key Features of Test Site Network

CATEGORY	LOCATION	LATITUDE (degrees)	ALTITUDE (feet)	KEY FEATURES
EXTREME WEATHER	CANAL ZONE (FT. CLAYTON)	9	~0	TYPICAL TROPIC: HOT AND HUMID; 100 INCH-PER-YEAR RAINFALL
	ALASKA (FT. GREELY)	64	1,270	SEMI-ARCTIC: DRY, COLD AND WINDY; -30 F WINTERS
MARINE	POINT VICENTE, CA	34	~0	COOL, DAMP MORNINGS AND CLEAR AFTERNOONS; CORROSIVE SALT SPRAY
	KEY WEST, FLA.	25	~0	HOT AND HUMID; CORROSIVE SALT SPRAY
	SAN NICHOLAS ISLAND, CA	34	~0	SOMEWHAT MILDER THAN KEY WEST
MOUNTAIN	TABLE MOUNTAIN, CA	34	7,500	TYPICAL ALPINE ENVIRONMENT: HEAVY WINTER SNOWS AND MILD SUMMERS; HIGH-VELOCITY WINDS
	MINES PEAK, CO	40	13,000	CLEAR AND COLD; HIGH-VELOCITY WINDS, MAX. UV
HIGH DESERT	GOLDSTONE, CA	35	3,400	VERY HOT AND DRY SUMMERS; CLEAR SKIES
	ALBUQUERQUE, NM	35	5,200	DRY WITH CLEAR SKIES; AN ABUNDANCE OF UV
	DUGWAY, UTAH	40	4,300	COLD WINTERS, HOT SUMMERS; ALKALINE SOIL
MIDWEST	CRANE, INDIANA	39	~0	TYPICAL MIDWEST: HOT HUMID SUMMERS, COLD SNOWY WINTERS
NORTHWEST	SEATTLE (FT. LEWIS)	47	~0	TYPICAL NORTHWEST: MILD TEMPERATURES AND AN ABUNDANCE OF RAIN
UPPER GREAT LAKES	HOUGHTON, MICHIGAN	47	750	MILD SUMMERS, SEVERE WINTERS
URBAN SOUTHERN CALIFORNIA	JPL/PASADENA	34	1,250	PRIMARY TEST SITE - HOT SUMMERS AND MILD WINTERS; VERY HIGH POLLUTION ENVIRONMENT
URBAN COASTAL	NEW LONDON, CONNECTICUT	41	~0	TYPICAL NEW ENGLAND COASTAL
	NEW ORLEANS, LOUISIANA	30	~0	HOT AND VERY HUMID; HIGH POLLUTION ENVIRONMENT

Table 2-2. Weather Highlights for 1978

	JPL	Table Mt.	Goldstone	Pt. Vicente	Alaska	Houghton	Canal Zone	Key West	Crane[a]	New London	Dugway	Seattle	New Orleans	Albuquerque	San Nicolas	Mines Peak
December																
Average Temperature, °F	56	37	42	58	8	14	78	[illegible]	18	26	35	44	44	37	53	11
High Temperature, °F	77	62	68	69	26	32	92	69	25	33	49	49	50	46	59	28
Low Temperature, °F	41	7	17	48	-17	-6	65	60	10	20	-13	40	38	27	48	-11
Average Humidity, %	40	50	37	-	75	79	80	77	78	73	69	74	75	55	72	No Data
Average Wind Speed, MPH	2	8	12	7	8	11	4	[illegible]	11	15	18	8	9	8	12	15[c]
Maximum Wind Speed, MPH	10	50[b]	25	23	62	49	11	29	44	42	39	35	29	30	52	39[c]
July																
Average Temperature, °F	79	70	87	63	61	63	78	85	77	73	96	66	83	89	62	52
High Temperature, °F	99	92	110	75	84	85	88	90	86	80	103	76	91	97	69	76
Low Temperature, °F	59	50	60	56	39	42	71	80	68	66	45	55	75	66	55	34
Average Humidity, %	44	26	14	-	71	63	76	71	71	72	34	57	80	19	80	No Data
Average Wind Speed, MPH	3	6	12	5	4	8	2	10	8	11	29	8	6	9	13	No Data
Maximum Wind Speed, MPH	8	25[b]	22	14	39	44	9	28	27	28	46	16	31	42	45	No Data
Yearly																
High Temperature, °F	104	92	110	91	84	95	95	90	84	81	103	76	[illegible]	97	70	75
Low Temperature, °F	44	7	20	35	-31	-6	66	58	9	18	-1	32	36	22	48	-30
Maximum Wind Speed, MPH	17	80[b]	No Data	52	62	49	5	32	44	44	50	35	39	52	52	130
Rainfall, in.	10	3	9	16	6	43	82	36	43	34	10	34	77	10	7	[illegible]
Snow, ft	-	6	-	-	No Data	32	-	-	2	4	14	-	-	-	-	39
Hail, days	-	1	-	-	-	-	-	-	-	-	-	-	-	11	-	-

[a]Weather for Indianapolis.
[b]Estimated.
[c]Data for Berthoud Pass.

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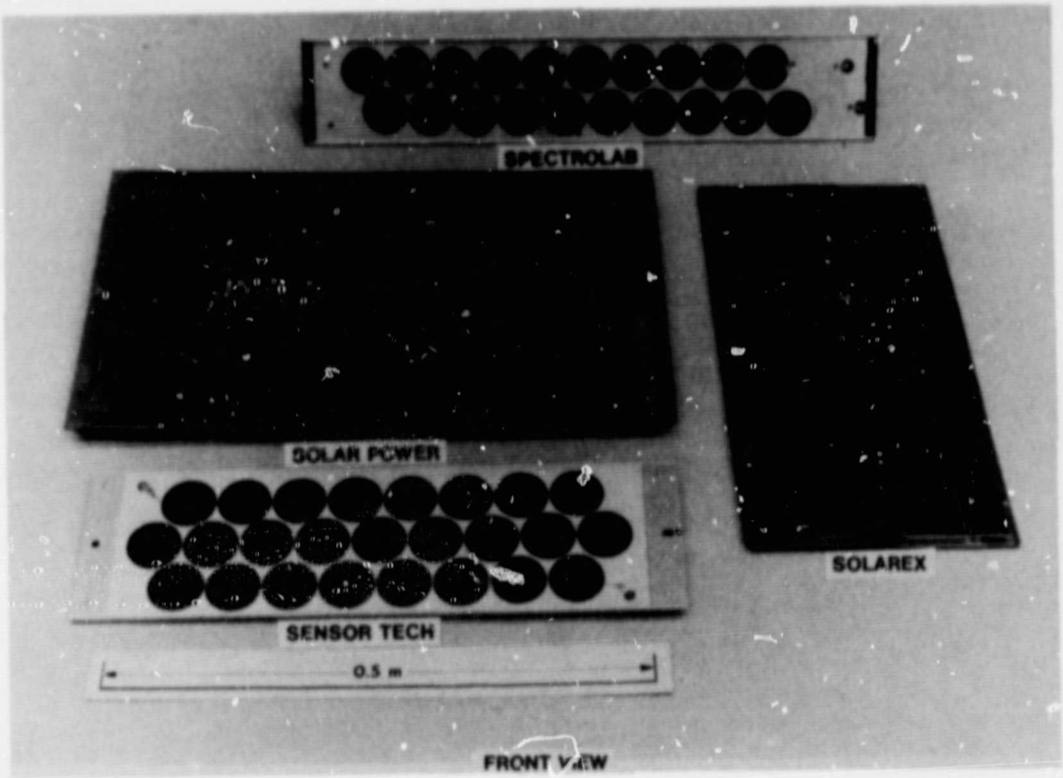
Table 2-3. Key Features of Principal Test Modules

Module Type	Electrical Performance[a] I_{sc}, amps	V_{oc}, volts	Peak Power, watts	Dimensions, mm	Physical Features
Block I					
Sensor Tech	0.51	14.0	5.4	571 x 165 x 11	Finned Al extrusion substrate 2.3-mm silicone encapsulant 25 cells, 50-mm diameter
Solar Power	1.61	13.0	14.5	610 x 375 x 6	Epoxy fiberglass substrate 3.2-mm silicone encapsulant 22 cells, 87-mm diameter
Solarex	1.42	10.3	9.3	508 x 260 x 5	Epoxy fiberglass substrate 2.3-mm silicone encapsulant 18 cells, 75-mm diameter
Spectrolab	0.66	11.6	5.45	663 x 124 x 69	Al "I-beam" extrusion substrate 2.3-mm glass over silicone encapsulant 20 cells, 50-mm diameter
Block II					
Sensor Tech	0.58	24.3	10.2	589 x 290 x 25	Stamped Al substrate 3.2-mm silicone encapsulant 44 cells, 56-mm diameter
Solar Power	1.96	23.3	33.9	1168 x 389 x 48	Molded polyester fiberglass substrate 2.3-mm silicone encapsulant 40 cells, 100-mm diameter
Solarex	1.40	23.7	22.0	582 x 582 x 33	Polyester fiberglass substrate, Al frame 2.3-mm silicone encapsulant 42 cells, 75-mm diameter
Spectrolab	1.88	23.2	30.7	1168 x 384 x 36	Formed Al frame 4.3-mm glass over PVB encapsulant 120 cells, 50-mm diameter
Block III					
ARCO Solar	1.40	23.2	22.2	1160 x 232 x 36	Formed Al box frame 10-mm glass/PVB/Tedlar laminate 41 cells, 75-mm diameter
Motorola	4.90	7.2	26.5	580 x 580 x 50	Formed stainless steel pan 4-3-mm glass front, silicone gel encapsulant 48 cells, 75-mm diameter
Sensor Tech	0.58	24.7	10.7	582 x 287 x 48	Finned Al extrusion substrate 5-mm silicone encapsulant 44 cells, 56-mm diameter
Solar Power	2.10	23.5	35.6	1168 x 389 x 48	Molded polyester fiberglass substrate 2.8-mm silicone encapsulant 40 cells, 100-mm diameter
Solarex	1.40	23.7	21.8	582 x 582 x 33	Polyester fiberglass substrate, Al frame 2.3-mm silicone encapsulant 42 cells, 75-mm diameter

[a]Based on 100 mW/cm^2 and 28°C; average values of modules at Southern California sites.



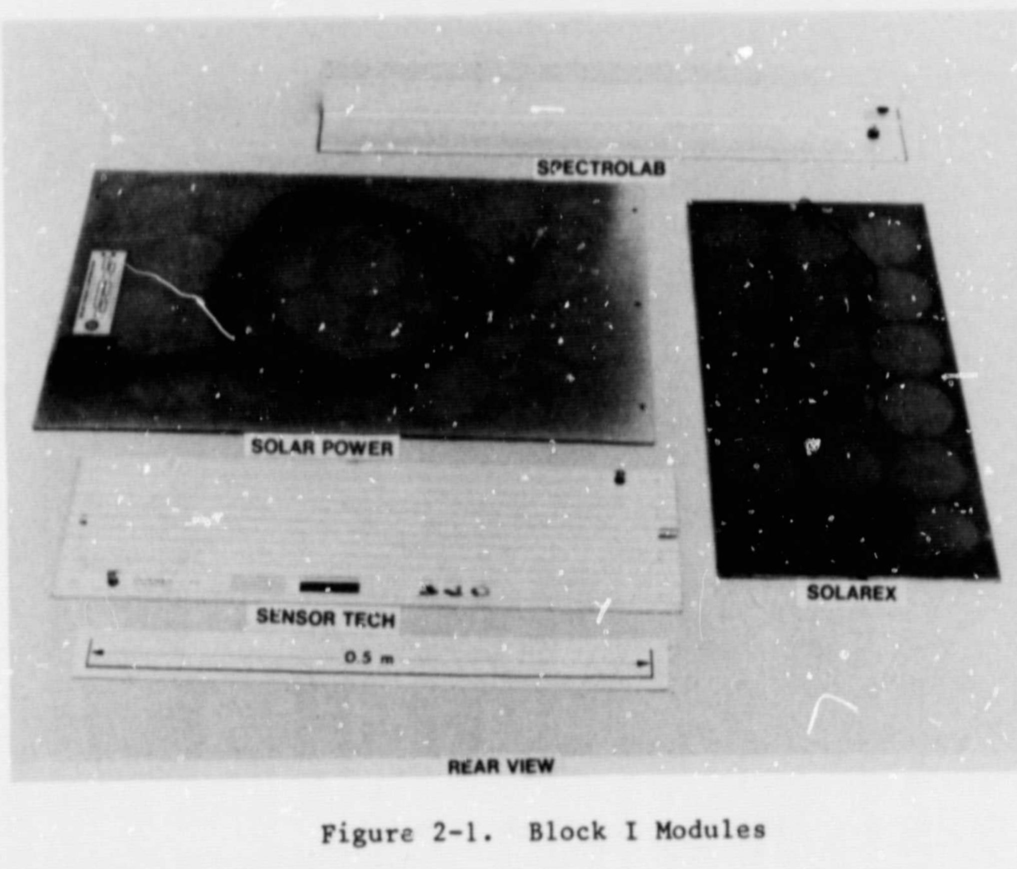


Figure 2-1. Block I Modules

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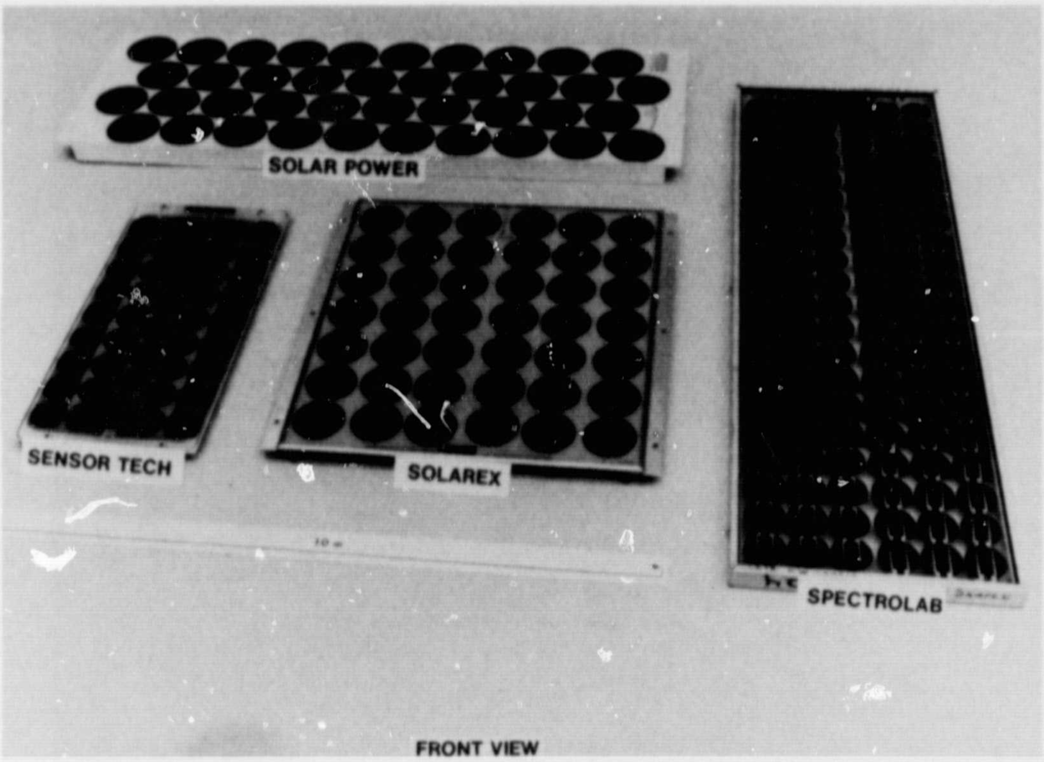

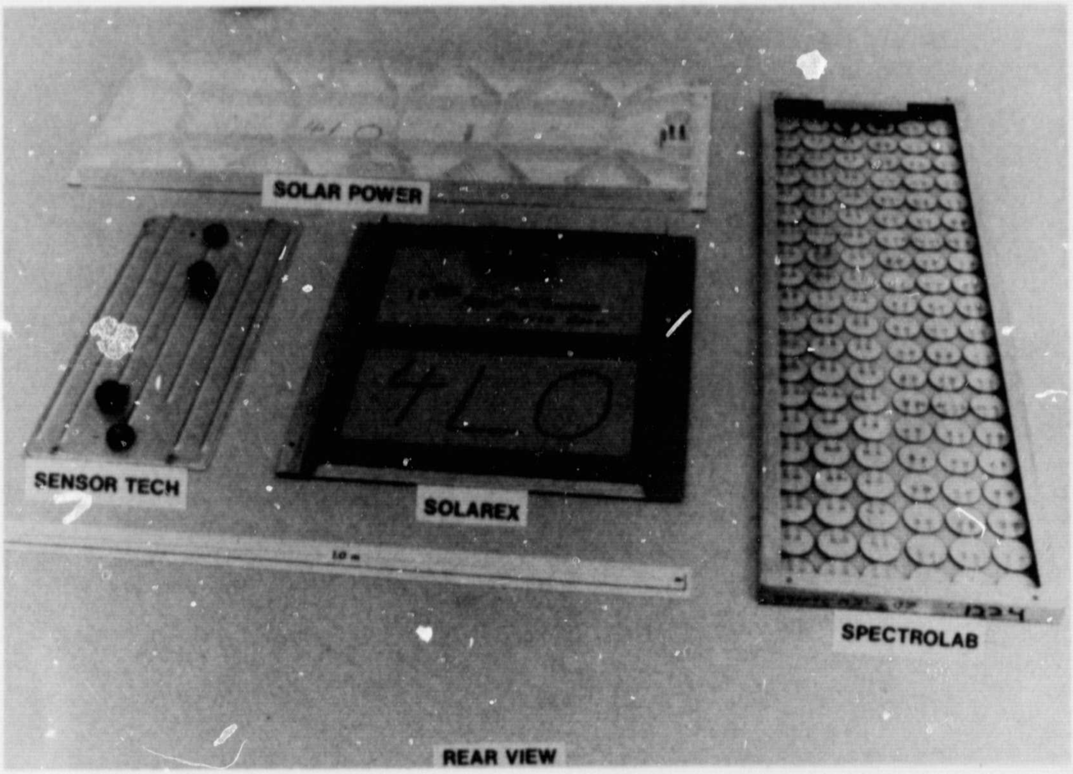

Figure 2-2. Block II Modules

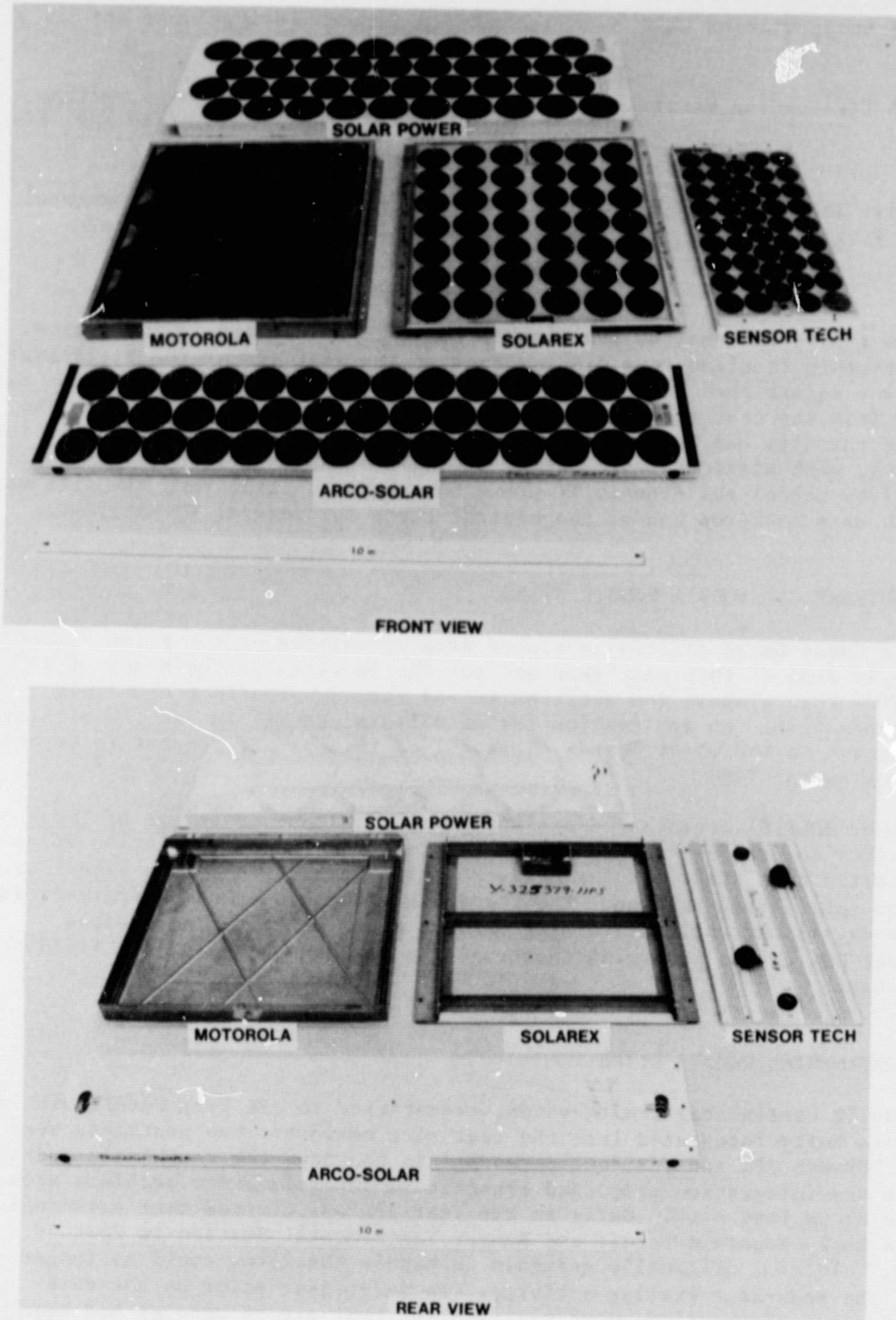

Figure 2-3. Block III Modules

LSA Encapsulation Task	Evaluate various encapsulants and encapsulation systems.
LSA Engineering Group	Determine the effects of high voltage operation on module insulation and life performance.
Solar Thermal Power System Program	Determine the effects of environmental contamination on various types of reflective surfaces.

The public information function of the site is gaining in importance. To support this function, the display room at the east end of the field test trailer was refurbished last year. An additional display emphasizing the data obtained from the test sites is being planned for the south wall. Over the past year the site has become one of the principal visitor attractions at the Laboratory, with visitors representing a complete cross section of the public, ranging from school children to TV crews to senators. Last year the site was used both as a backdrop and as the central theme for several TV programs.

B. SOUTHERN CALIFORNIA REMOTE SITES

The Coast Guard officially closed down operations at the Point Vicente facility in June of this past year and put the facility in the hands of a caretaker. This closure was anticipated and should not affect the field testing operation. An application for an official permit to use the site area was submitted to the Coast Guard. Approval of this permit request is expected before the end of 1980.

Other JPL/LSA organizations are beginning to take advantage of these remote sites to perform their own experiments. The LSA Encapsulation Group has installed test stands at the three Southern California remote sites for their own specialized testing. The LSA Engineering Group, using spare field test stands, is currently performing soiling experiments at these sites. Additional LSA groups are being encouraged to take advantage of the field test capabilities.

C. CONTINENTAL REMOTE SITES

The 12 continental remote sites, transferred to JPL from NASA/Lewis in 1979, were fully integrated into the test site network. New contracts were written between JPL and resident personnel to continue the monthly inspections. Although the integration proceeded smoothly in general, a few problems arose with the Mines Peak site. Early in the year JPL was advised that personnel from the Rocky Mountain Forest and Ranger Experimental Station in Fort Collins, Colorado, originally assigned to handle the site, could no longer support the endurance testing activity. In July, just prior to the data-gathering tour of the site, word was received that all 16 modules had been stolen. Other arrangements for monitoring activities at this site are being developed.

Module theft has been a problem at several of the sites. Since JPL took over the network in 1979, 25 modules in addition to the 16 stolen at Mines Peak have been stolen at four sites; nine of these were subsequently recovered. One of the sites where theft occurred is within a closed NASA facility and another is on a remote Navy island. A program has been started to develop or procure new security devices to protect the modules from thievery.

SECTION III

DATA ACQUISITION TECHNIQUE AND INSTRUMENTATION DEVELOPMENT

A. EFFECTS ON ELECTRICAL PERFORMANCE OF SHADOWING THE INDIRECT COMPONENT OF IRRADIANCE

Electrical performance data taken on modules at the JPL site during the winter months of 1978-1979 show apparent errors in the daily data several times greater than what would be expected. A review of the data suggested that the problem arose from the reference cell insolation values used to normalize the data. The LSA Performance Measurement Group was called in to perform an investigation of the problem. Their conclusions are summarized in the following text.

During the winter months when the modules are at large tilt angles and the sun is low in the sky, the modules in front of the modules being tested shadow the indirect component of irradiance. The distance between module rows is fairly short (8 feet) and the length of the edge of the frames is relatively long (4 feet). The reference cells are mounted on top of the stands and are never shadowed. Therefore, according to study conclusions, the reference cells see one level of insolation and the bottom of the modules see another. Figure 3-1 shows the geometry of the stands, reference cells and sun on December 22.

A preliminary verification of the hypothesis was made by the Performance Measurement Group last winter by sliding a reference cell up and down some of the modules and noting the change in insolation. Variations as large as

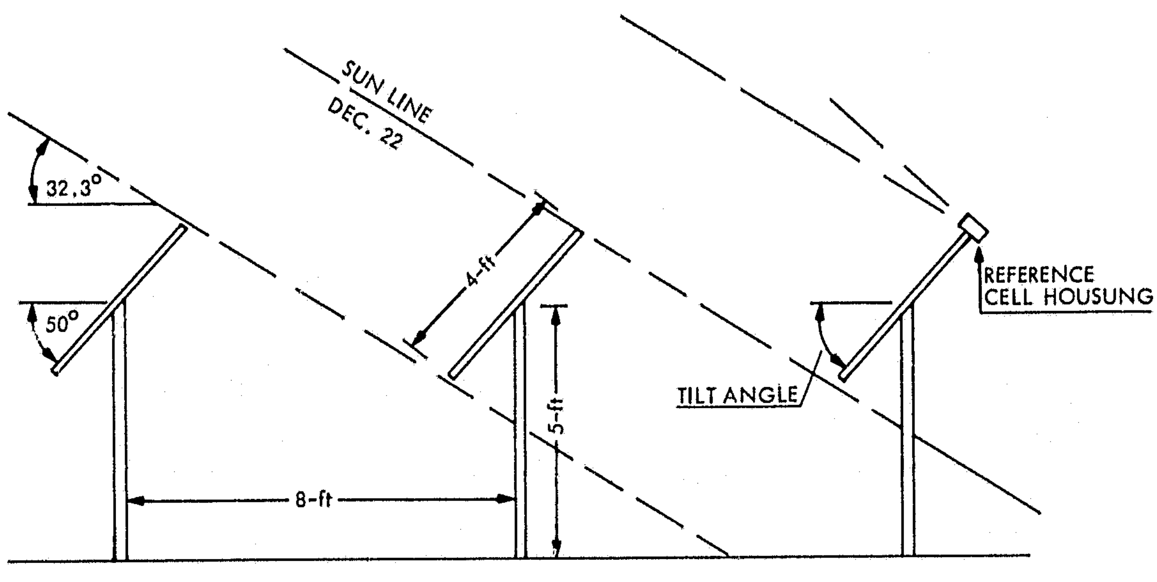

Figure 3-1. Geometry of Stands, Reference Cells and Sun on December 22, 1979

8 percent were measured. A more comprehensive examination was initiated which entailed tracking the electrical performance of some selected modules throughout the year. The analysis of Module 189 exemplifies the results. Figure 3-2 shows the normalized short-circuit-current history of Module 189, a glass Spectrolab II module, for a one year period, July 1, 1979 to June 30, 1980. Module 189 is located in the center of the field and is subject to the maximum amount of indirect shadowing possible. The lines between data points are included to provide visual continuity. The dashed line in the plot corresponds to the mean of the data. The sun elevation angle at solar noon and the module tilt position are shown at the bottom of the figure. The tilt strategy employed was designed to maintain a sun module misalignment of less than 10 degrees at solar noon. The circled data points are points where the insolation was unsteady during the daily acquisition; this will be discussed later.

The mean data line in Figure 3-2 clearly correlates with the sun elevation-angle. At winter solstice, when the maximum shadowing effect occurred, the short-circuit-current value dropped about five percent from the summer mean. This result is quantitatively consistent with what would be expected if the indirect shadowing hypothesis is correct. Data on other modules in the field corroborate this result. Two conclusions may be drawn from this investigation: (1) shadowing the indirect component of irradiance can reduce the electrical output of modules and result in anomolous performance data; and (2) power losses in array applications can result from indirect irradiance shadowing if the module rows are close together. Further investigation of this problem will be performed in the future.

So far, no satisfactory solution has been found to the question of what should be done about the performance data in the winter at the JPL site. However, as discussed later in this report, it is not necessary to accurately track short-circuit current and peak power (those parameters affected by shadowing) to determine if a module has degraded. Understanding the reason for the apparent data error and knowing the approximate magnitude may be sufficient to evaluate the electrical performance of a module.

B. ELECTRICAL PERFORMANCE DATA ACCURACY AND MODULE DEGRADATION

An important byproduct of the shadowing investigation is a better understanding of the accuracy of the electrical performance data obtained at the JPL site. To set the framework for discussing the accuracy question, the histories of the key electrical performance parameters, short-circuit current, open-circuit voltage, peak power and fill factor of two modules are presented for a one year period in Figures 3-3 and 3-4. Module 189 is the Spectrolab II module with glass superstrate used in the previous discussion, and Module 212 is a silicone-encapsulated Solarex II module. The data in these figures have been normalized to 90 mW/cm^2 and the average yearly operating temperature for each of the modules.

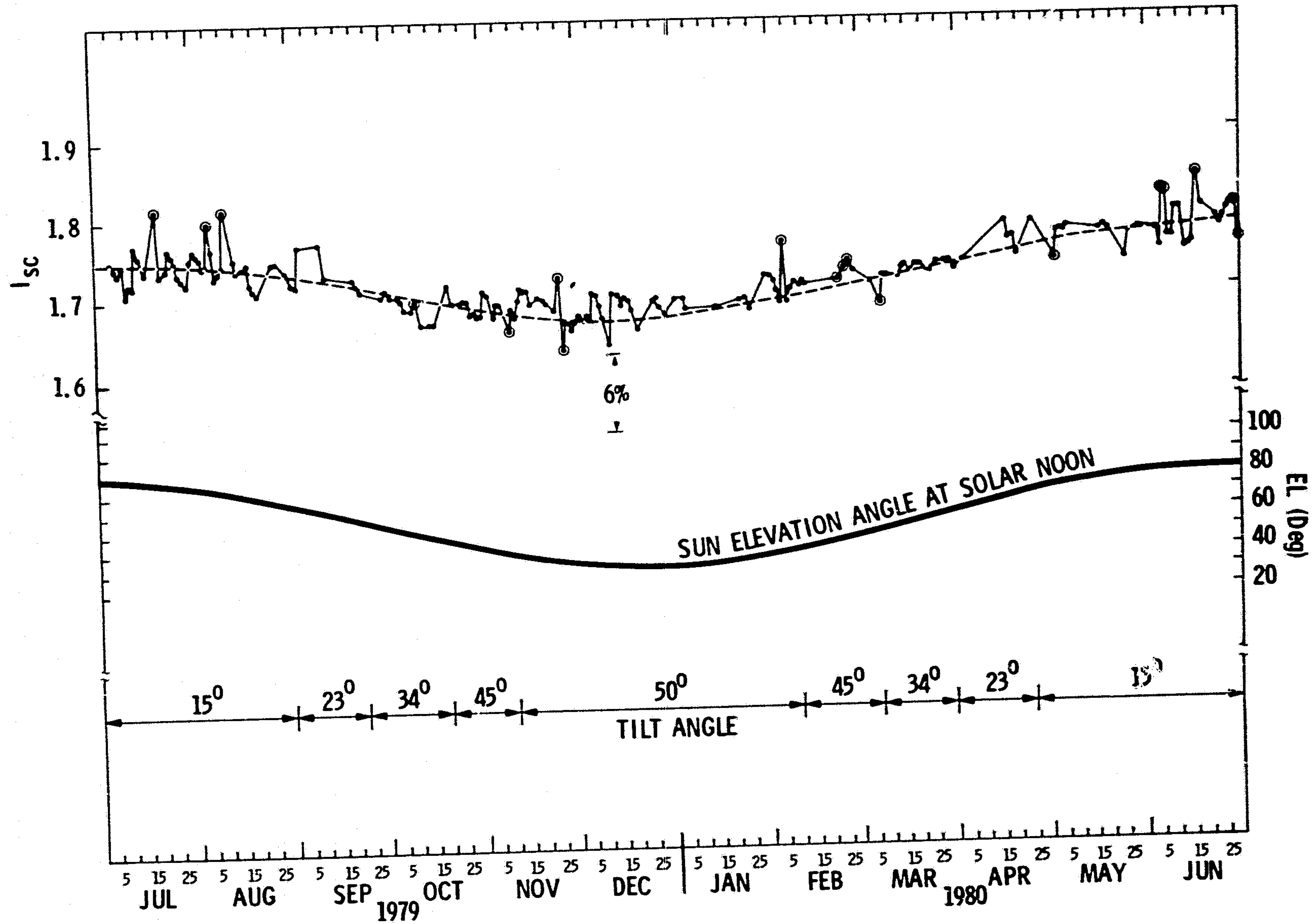

Figure 3-2. Short-Circuit-Current History of Spectrolab II Module 189 Depicting Shadowing Effect

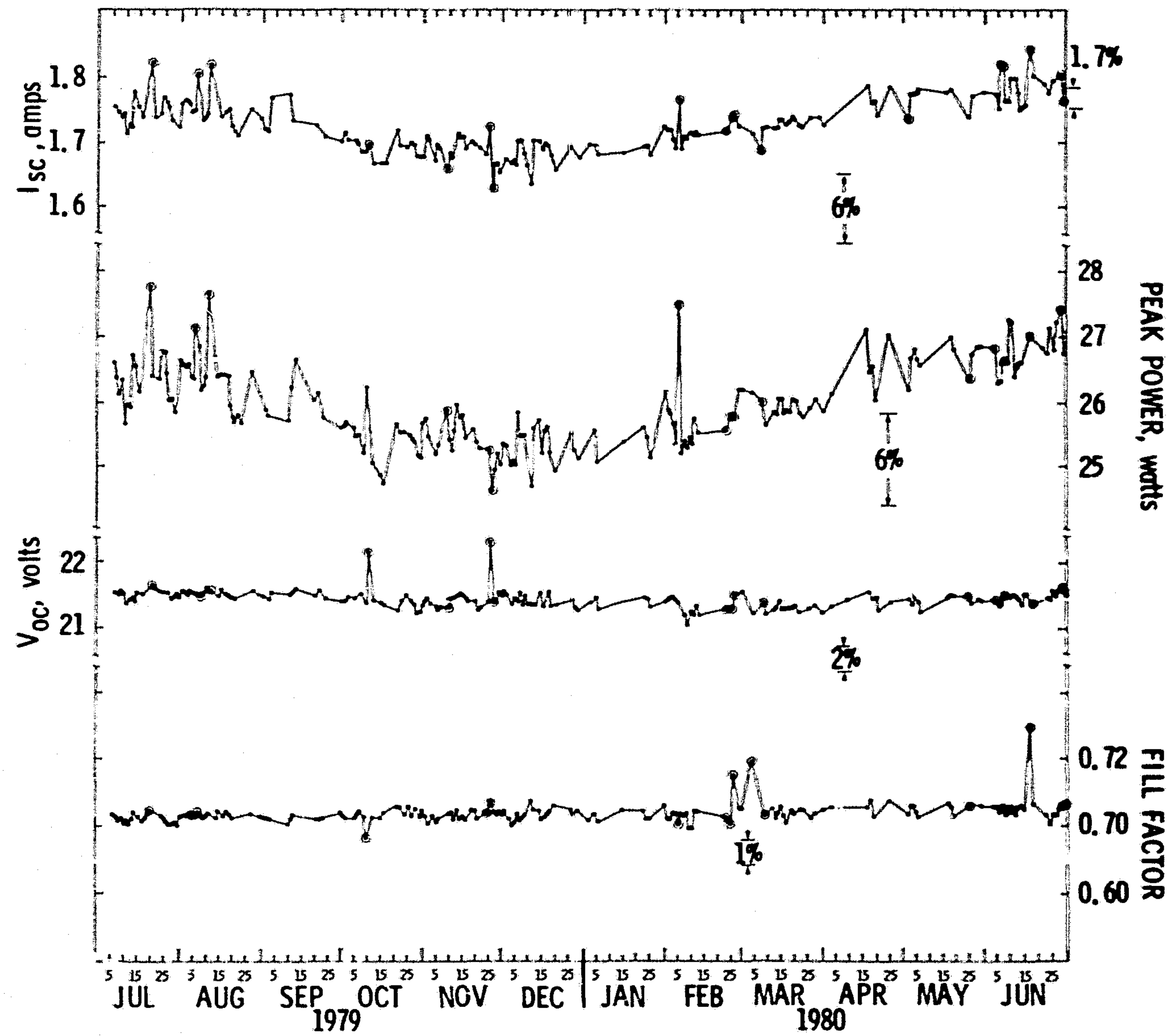

Figure 3-3. Electrical Performance Data Obtained With the JPL Data Acquisition System for a One-Year Period on Spectrolab II Module 189

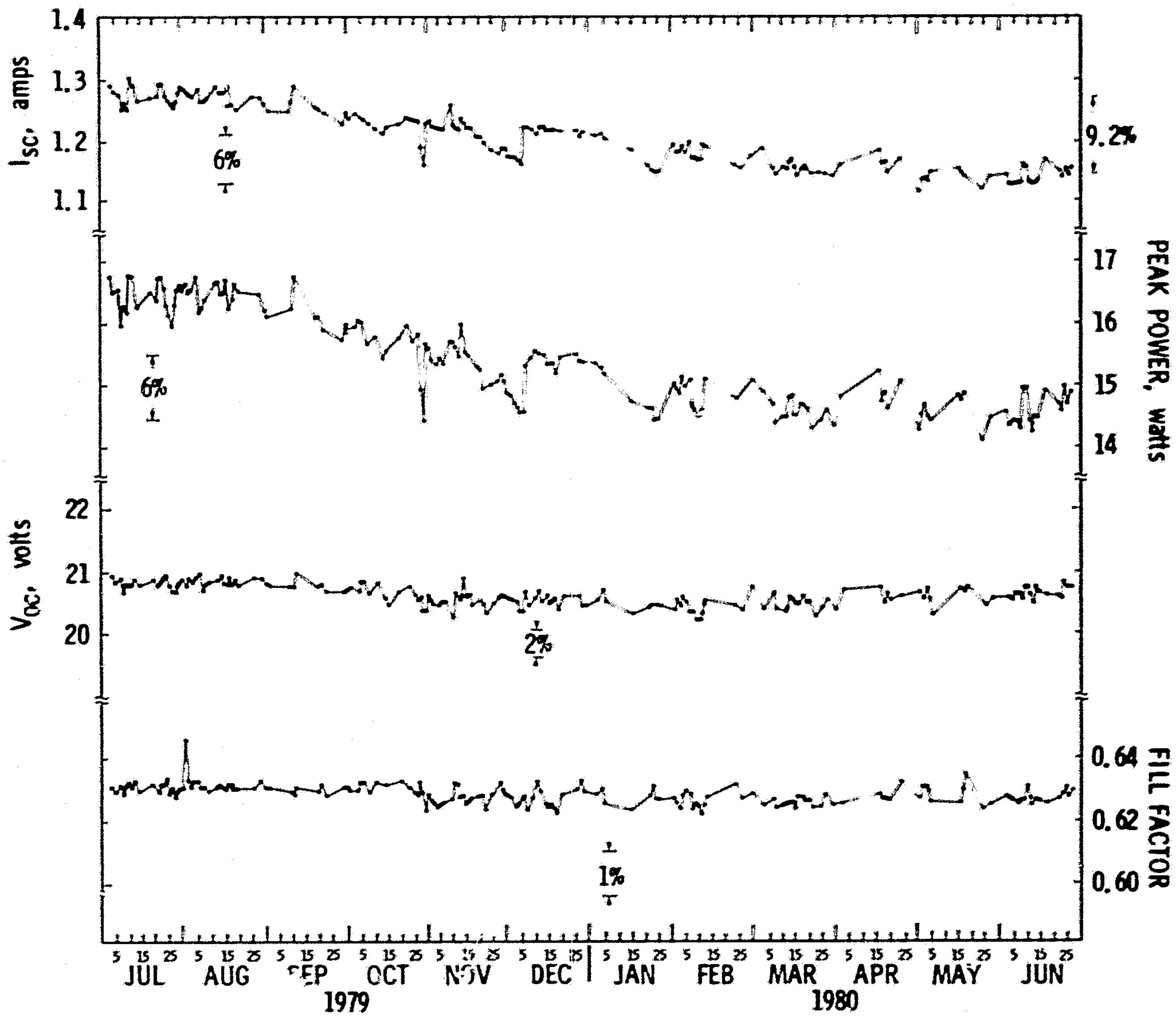

Figure 3-4. Electrical Performance Data Obtained With the JPL Data Acquisition System for a One-Year Period on Solarex II Module 212

1. Effects of Unsteady Insolation

A review of performance data obtained last year indicated that the scatter of the data from the mean was greater than expected, and that often, on days when the data deviated significantly, the insolation was unsteady. Generally the unsteadiness, caused by cloud movement, was not very large; usually the insolation variation was between 5 and 20 mW/cm^2 for the full 5 minutes it takes to acquire data from the whole field. In the case of a module, for which the acquisition time is in the order of a second, the insolation variation is almost insignificant. One reasonable explanation is that the clouds associated with the unsteady insolation caused a significant shift from the usual spectral distribution of irradiance, which was sensed differently by the reference cells and modules; the spectral shift caused an exaggeration of the module/reference cell mismatch. It should be noted that the data system will not trigger acquisition if the insolation is below 70 mW/cm^2. Therefore, except for those few days when there was sufficient cloud movement to block the sun during acquisition, the insolation levels remained moderately high. The effect described above is graphically displayed in Figure 3-3 (Module 189), where the circled points correspond to days in which the irsolation was unsteady. It becomes obvious that if those points are eliminated from the plots, the data scatter is greatly reduced. This effect was also present in most of the data of the other modules analyzed.

2. Effects of Embedded Dirt

The accumulation of embedded (or primary) dirt on silicon rubber modules decreases the optical transmittance and causes a decrease in performance. An example of this effect is shown in the short-circuit-current and peak-power data of Module 212 in Figure 3-4. (Data corresponding to the circled days in Figure 3-3 were excluded from the plots in Figure 3-4.) For the one-year period covered in Figure 3-4, the short-circuit current dropped 9 percent; a comparable drop in peak power also occurred. This decrease in performance was verified independently by the LAPSS system. Module 212 was taken out of the field, tested with the LAPSS system, and returned to the field; the LAPSS data indicated an 8.2 percent decrease in performance. For comparison, a Sensor Tech II module and a Solar Power II module were also tested with the LAPSS; the short-circuit-current decreases for these modules was similar: 10.1 percent for the Sensor Tech and 8.3 percent for the Solar Power.

The reverse effect has been observed with the glass Spectrolab II modules; they have actually increased in performance. Module 189, for instance, gained 1.7 percent in short-circuit current. (This increase was verified with the LAPSS.) A year before, short-circuit current increased 1.4 percent.

It is very difficult to factor out of the performance data the effects of embedded dirt, as the accumulation of embedded dirt is not necessarily linear. Data obtained a year before on Modules 212 and the two other silicon encapsulated modules discussed above showed that total annual short-circuit-current losses were 1-1/2 to 2 times last year's losses. Using the previous year's data to project last year's effects would have been completely erroneous.

Fortunately, it is not necessary to track accurately all the performance parameters to determine degradation. This will be discussed further in Section V.

3. Data Accuracy

From plots similar to those shown in Figures 3-3 and 3-4 for a cross-section of modules, an evaluation of the accuracy of the electrical performance data at the JPL site was made. The quality of the data shown in the figures is representative of the quality of the data obtained in general. The evaluation indicated that data usually fell in the following bands:

Short-circuit current	±3 percent
Open-circuit voltage	±1 percent
Peak power	±3 percent
Fill factor	±1 percent

These values assume steady sky conditions and do not take into account either indirect shadowing or embedded dirt. Indirect shadowing can introduce an error in short-circuit current and peak power of as much as 8 percent in winter, and embedded dirt can introduce an error on these parameters in excess of 20 percent, depending upon the encapsulant material, the weather, and atmospheric pollutant history. Both open-circuit current and fill factor are insensitive to the effects of shadowing and embedded dirt and, to some extent, the effects of unsteady insolation. It is the insensitivity of the fill factor to these effects that provides the mechanism for determining module degradation.

4. Determining Module Degradation

The procedure that has been adopted, and which has been borne out by the yearly performance histories typified in Figures 3-3 and 3-4, was to use a change in the fill factor to detect a degraded module. At the JPL site a nominal delta fill factor of 3 percent was used; at the remote sites, because of additional testing inaccuracies, 5 percent was used. An example follows.

Figure 3-5 contains the short-circuit-current and fill-factor histories of a Sensor Tech II Module (Module 166) that is "degraded." Contrasted with the fill-factor histories of Modules 189 and 212, Module 166's fill-factor history is erratic and varies by almost 40 percent. This behavior is typical of modules that are going bad. Nondegraded modules, on the other hand, have solid unvarying fill factors. Unfortunately, it is easy to be misled; there are many days when the fill factor of Module 166 was unchanged from its original nondegraded state. Caution must be exercised in deciding whether a module is good or bad from a single data point. The majority of modules that are failing demonstrate similar erratic behavior, oscillating from an apparent nondegraded state to a degraded one. A possible explanation is that these modules have internal mechanical fractures, such as broken interconnects or

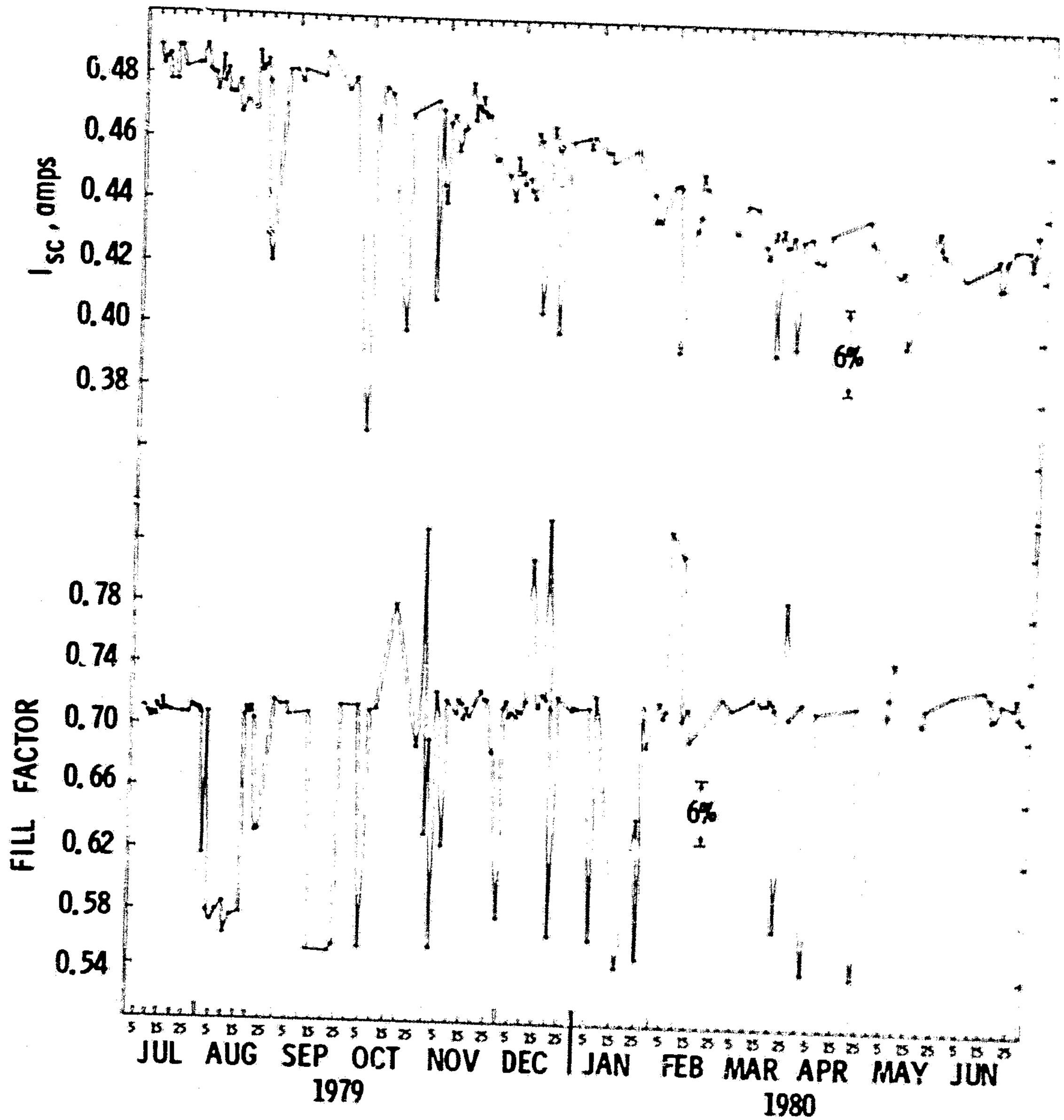

Figure 3-5. Short-Circuit-Current and Fill-Factor Histories of Degraded Sensor Tech II Module 166

cracked cells, that cause the electrical contacts between the fractured parts to be poor. Consistent with this hypothesis is the observation that degraded modules often appear nondegraded in the morning when it is cool and show degradation at mid-day when it is warm. Generally, modules that exhibit this pattern become worse and eventually fail.

C. PORTABLE I-V DATA LOGGER

The most important new piece of equipment obtained by the Field Test Group in the last two years is the Portable I-V Data Logger (Figure 3-6). With it, I-V data comparable in quality to that obtained at the JPL site can be obtained in remote locations, stored in the solid state storage units, and later off-loaded into the JPL site data acquisition system for processing and archiving. The instrument, which was fabricated by the JPL Instrumentation Section, was received in March 1980 and placed into service as an operational tool two months later. During the spring and summer of 1980, the instrument was taken on its first data gathering tour of the remote sites. Approximately 1200 I-V curves were made at the remote sites. The data obtained during the tour is the most accurate ever obtained from these sites.

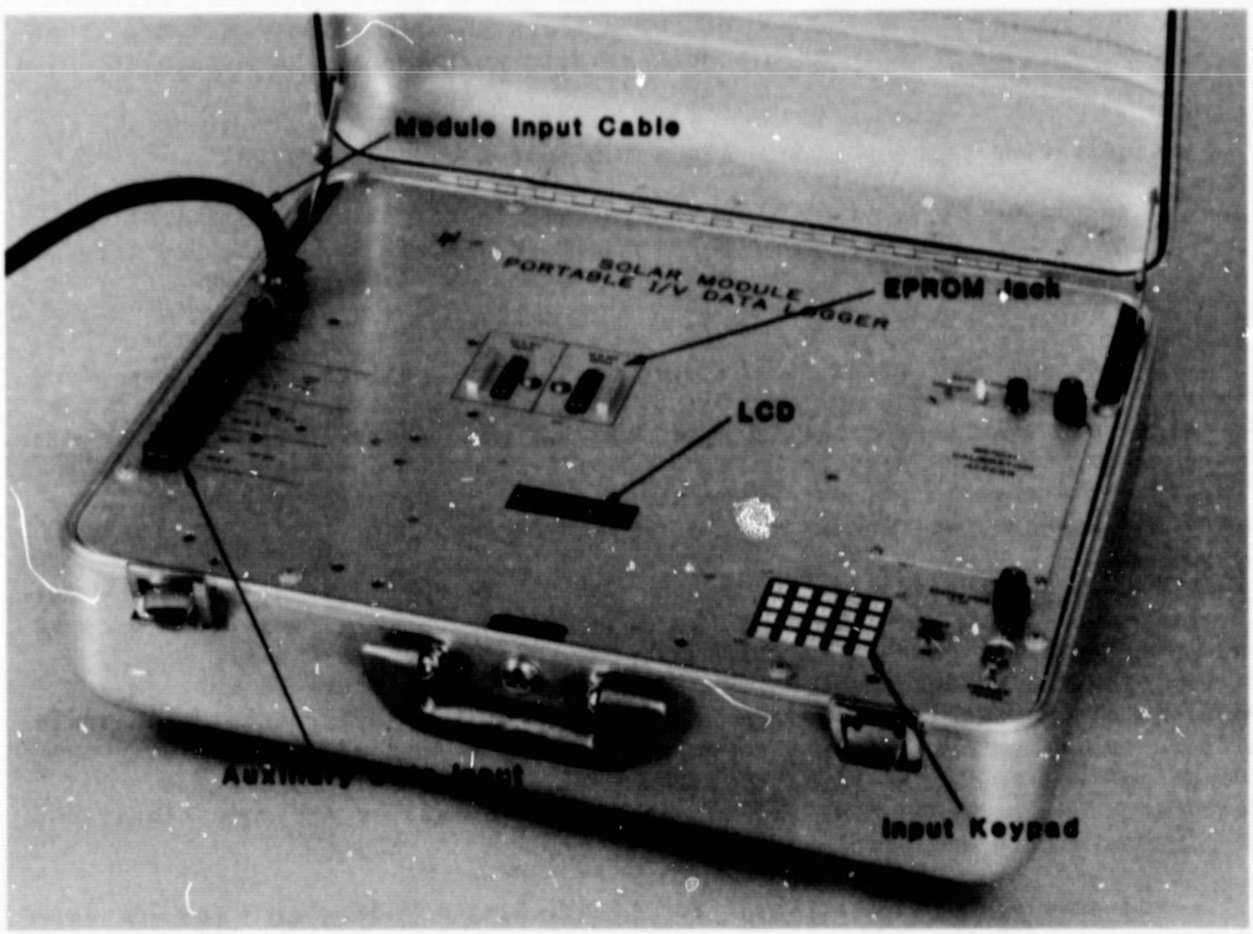

Figure 3-6. Portable I-V Data Logger

The Data Logger is a compact self-contained instrument which weighs 49 pounds, including batteries and recharging electronics. It is encased in an aluminum traveling container measuring 17 x 21 x 7-1/2 inches. Other key features include:

Operating ranges:	Voltage, 15 and 30 volts; current, 2 and 10 amperes. Range selection performed internally.
Accuracy:	$\pm$0.5 percent of full scale of selected range.
Auxiliary data inputs:	Two thermocouple channels; two pyranometer (10 mV) channels; two reference cell (100 mV) channels.
Storage media:	Solid state EPROM units in two sizes, 16K or 32K. 12 to 14 I-V curves can be stored in one 16K unit.
Acquisition process:	Microcomputer controlled. Final curve derived from two I-V curves, one incrementing on current and the other on voltage. Features of the process are redundancy at knee, cross-check on data quality, and high resolution of data at curve ends.
Acquisition time:	About 1 second for an I-V curve.
Data playback:	Option available to display electrical performance parameters and auxiliary data obtained during last interrogation.

Figure 3-7 contains a typical set of data. In Figure 3-8 the data from Figure 3-7, shown as the solid line, is compared with data obtained with the JPL site data acquisition system. The circled points were taken with the data system about 15 seconds after d ,a were collected with the Data Logger (for clarity, only a small percentage of the data system data is presented). The agreement between the two systems is excellent.

The more critical question is how does field data obtained with the Data Logger compare with LAPSS data on the same module. This is important because most pre-installation data is obtained with the LAPSS, and the key to determining module degradation lies in measuring the difference between a module's pre-installation performance and its current performance. The basic difficulty in making this comparison is that LAPSS data is obtained at 100 mW/cm^2 and 28^{o}C, and field data can be obtained at any insolation level and temperature. However, usually the temperatures are much higher and the insolation values somewhat lower.

The same problems that exist for translating I-V data with the JPL data system exist with the Data Logger: determining the appropriate effective irradiance, determining the appropriate module temperature for translating purposes, and acquiring and using the correct translation constants.

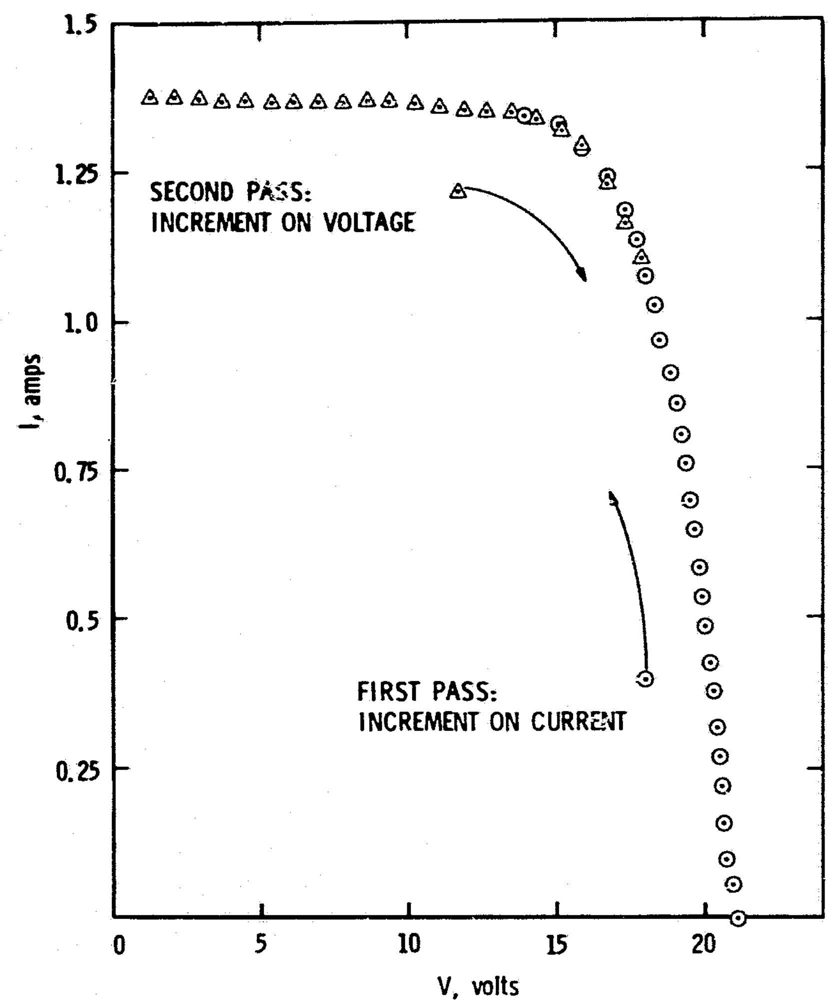

Figure 3-7. Typical Data Generated by the I-V Data Logger

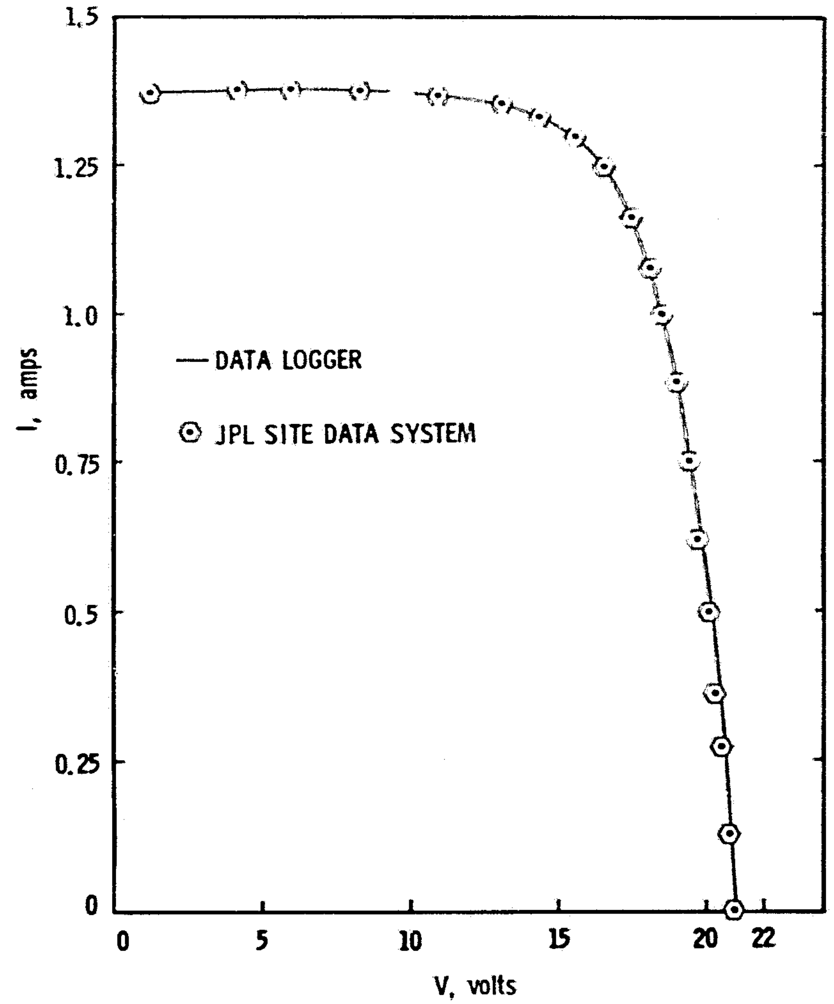

Figure 3-8. Comparison Between Data Logger and JPL Site Data System

Effective irradiance is usually determined by means of a matched reference cell for the type of module being tested. However, because of the unavailability of reference cells for all the different types of modules at the remote sites, it was decided that the Li-Cor pyranometer would be used to determine irradiance. To enhance the Li-Cor data, correction factors appropriate for each type of module were determined by comparing the output of the Li-Cor with the outputs of the different reference cells currently in use at the JPL site. The temperatures used to translate the data were determined by adding the experimental backside temperatures to the difference between the backside temperature and the cell temperatures. Data relating the difference between backside and cell temperatures were obtained from experiments performed by the LSA Engineering Group.

Several modules were tested at JPL with both the Data Logger and the LAPSS to determine how accurately the translations could be performed. In most cases, short-circuit current and peak power deviated by less than ± 4 percent, and open-circuit voltage and fill factor deviated by half that amount.

Recently an opportunity presented itself to validate the process in a field-use setting. Electrical performance data were obtained with the Data Logger on 48 Block II Sensor Tech modules at an installation in Lone Pine, California. The test conditions were excellent; the insolation was about 100 mW/cm^2 and the air temperature was in the mid-eighties ($^{\circ}F$). The module temperatures were about 60°C. Six of the modules were later removed from the installation and sent to JPL where they were tested with the LAPSS. Table 3-1 summarizes the results of the LAPSS tests. The "percent differences" are the differences between the LAPSS values and the Data-Logger values. A minus means that the Data Logger value was larger. The range of differences was somewhat larger than those obtained during the JPL tests but not to a significant extent. Only one peak-power value deviated by more than 5 percent. It should be pointed out that all or most of the 5 percent could be accounted for by Li-Cor/module spectral response mismatch. All the fill-factor differences were less than 1-1/2 percent, confirming once again that the fill factor may be the most important parameter for determining change.

	I_{sc}, amps		V_{oc}, volts		Peak Power, watts		Fill Factor	
Module Serial Number	Data Logger	% Diff.	Data Logger	% Diff.	Data Logger	% Diff.	Data Logger	% Diff.
009	.552	4.1	23.61	-0.5	10.19	4.7	.782	1.1
020	.510	3.2	23.75	-0.7	9.87	2.5	.815	0
030	.553	2.3	23.74	-3.9	10.01	-0.6	.763	0.9
069	.583	4.0	23.90	-1.3	10.52	4.3	.758	1.4
141	.560	3.9	23.4	0 3	10.06	5.2	.767	1.0
153	.598	1.0	23.2	-1.5	10.37	0.7	.747	1.3

Table 3-1. Comparison Between Data Logger and LAPSS

SECTION IV

ENDURANCE TEST DATA

A. FAILURE AND DEGRADATION STATISTICS

The failure and degradation data obtained last year were the most comprehensive acquired to date. At JPL, 207 days of I-V data were collected on each module; and at the remote sites, I-V data were collected on every module with the new portable I-V Data Logger. Approximately 1200 I-V curves were taken with the Data Logger.* From this wealth of data an up-to-date electrical performance status report was made on each module. A summary of the data is presented in Tables 4-1 through 4-5 and in Figure 4-1.

Table 4-1 contains an overview of the performance data, including the totals by site category for each module type. Also included is background information indicating when and how many modules were deployed, how many modules are currently under test, and how many were stolen. A breakdown of Table 4-1 data from the Southern California remote sites and the Continental remote sites is given in Tables 4-2 and 4-3. Figure 4-1 is a graphic presentation of the module failure data showing failure rate curves for the three large-scale procurements. A tabular breakdown of the failure data by module type is presented in Table 4-4. Finally, a breakdown of the failure data by site is given in Table 4-5.

The key results and conclusions from the failure data are:

(1) There has been a continual decline in the failure rate with each new large-scale procurement.

- The Block I mean failure rate is 5.0 percent.
- The Block II mean failure rate is 1.7 percent.
- No Block III modules failed.

(2) The Solar Power modules (both Blocks I and II) are the single largest contributor to the failure statistics. If they were removed from the count, both the Block I and Block II failure rates would be cut by more than half.

(3) The Spectrolab modules have the best record. Only 10 percent of the Block I modules that failed were Spectrolab modules. No Block II Spectrolab modules failed.

(4) The data is insufficient at this time to correlate failures with environment.

*To improve the reliability of the results, each module was usually tested on two different days.

Table 4-1. Electrical Performance Summary of All Modules

	Sensor Tech I	Spectrolab I	Solarex I	Solar Power I	G.E. Shingles I	Sensor Tech II	Spectrolab II	Solarex II	Solar Power II	Sensor Tech III	Solarex III	Solar Power III	ARCO Solar III	Motorola III	Total
JPL															
No. deployed	64	41	39	21	40	34	13	19	14				10	8	303
Deployment date	10-76 12-78	10-76 5-78	10-76 11-77	10-76 12-78	10-78	2-77 8-77	5-77 11-77	6-77 12-78	5-77 10-77				10-78	10-78 2-79	-
No. failed as of 9/79	6	3	6	14	0	0	0	2	2				0	0	33
No. failed since 9/79	2	1	2	2	0	2	0	1	0				0	0	10
No. currently under test	56	37	31	5	40	32	13	16	12				10	8	260
No. currently degraded	4	1	1	0	a	19	0	0	3				1	0	29
Southern California Sites															
No. deployed	28	37	16	15		24	9	12	9	24	12	9			195
Deployment date	11-76 4-77	11-76 4-77	11-76 12-76	11-76 11-77		4-77 8-78	11-77 8-78	9-77 8-78	9-77 8-78	11-78	11-78	11-78			-
No. failed as of 9/79	1	0	0	11		0	0	0	0	0	0	0			12
No. failed since 9/79	0	0	0	0		0	0	0	0	0	0	0			0
No. currently under test	27	36	16	4		24	9	12	9	8	4	3			152
No. currently degraded	0	0	0	2		0	1	0	0	0	0	0			3
Continental Sites															
No. deployed						48	48	48	48						192
Deployment date						10-77 5-78	10-77 5-78	10-77 5-78	10-77 5-78						-
No. failed as of 9/79						0	0	0	2						2
No. failed since 9/79						0	0	0	3						3
No. currently under test						36	38	37	34						145
No. currently degraded						3	1	0	6						9
No. stolen						8	6	7	5						26

[a]Only tests of the whole array were made, the exact condition of each module is unknown.

Table 4-2. Electrical Performance Summary of the Southern California Remote Sites

	Sensor Tech I	Spectrolab I	Solarex I	Solar Power I	Sensor Tech II	Spectrolab II	Solarex II	Solar Power II	Sensor Tech III	Solarex III	Solar Power III	ARCO Solar III	Motorola III	Total
Table Mountain														
No. deployed	14	18	8	9	8	3	4	3	8	4	3			82
Deployment date	11-76 3-77	11-76 3-77	11-76	11-76 11-77	4-77	11-77	9-77	9-77	10-78	10-78	10-78			-
No. failed as of 9/79	1	0	0	9	0	0	0	0	0	0	0			10
No. failed since 9/79	0	0	0	0	0	0	0	0	0	0	0			0
No. currently under test	13	18	8	0	8	3	4	3	8	4	3			72
No. currently degraded	0	0	0	0	0	0	0	0	0	0	0			0
Goldstone														
No. deployed	14	19	8	6	8	3	4	3	8	4	3			80
Deployment date	12-76 4-77	12-76 4-77	12-76	12-76	9-77	4-77	9-77	9-77	1-79	1-79	1-79			-
No. failed as of 9/79	0	0	0	2	0	0	0	0	0	0	0			2
No. failed since 9/79	0	0	0	0	0	0	0	0	0	0	0			0
No. currently under test	14	18	8	4	8	3	4	3	8	4	3			77
No. currently degraded	0	1	0	2	0	1	0	0	0	0	0			4
Point Vicente														
No. deployed					8	3	4	3	8	4	3			33
Deployment date					8-78	8-78	8-78	8-78	11-78	11-78	11-78			-
No. failed as of 9/79					0	0	0	0	0	0	0			0
No. failed since 9/79					0	0	0	0	0	0	0			0
No. currently under test					8	3	4	3	8	4	3			33
No. currently degraded					0	1	0	0	0	0	0			1

Table 4-3. Electrical Performance Summary of the Continental Remote Sites

	Sensor Tech II						Spectrolab II					
	Deployment date[a]	No. failed as of 9/79	No. failed since 9/79	No. stolen	No. currently under test	No. currently degraded	Deployment date[a]	No. failed as of 9/79	No. failed since 9/79	No. stolen	No. currently under test	No. currently degraded
Canal Zone	12-77				4		12-77				4	
Key West	12-77			1	3		12-77				4	
New Orleans	2-78			2	2	1[c]	2-78				4	
Crane	12-77				4		12-77				4	
Houghton	11-77			1	3	2	11-77				4	
New London	1-78				b		1-78				b	
Albuquerque	2-78				4		2-78				4	
Dugway	1-78				4		1-78				4	
Alaska	10-77				4		10-77				4	
Seattle	1-78				4		1-78				4	1[c]
San Nicolas Island	4-78				4		4-78			2	2	
Mines Peak	5-78			4			5-78			4		
Totals		0	0	8	36	3		0	0	6	38	1

	Solarex II						Solar Power II					
	Deployment date[a]	No. failed as of 9/79	No. failed since 9/79	No. stolen	No. currently under test	No. currently degraded	Deployment date[a]	No. failed as of 9/79	No. failed since 9/79	No. stolen	No. currently under test	No. currently degraded
Canal Zone	12-77				4		12-77	1	1		2	1
Key West	12-77			1	3		12-77		1	1	2	
New Orleans	2-78				4		2-78		1		3	1
Crane	12-77				4		12-77				4	
Houghton	11-77				4		11-77				4	3
New London	1-78				b		1-78				b	
Albuquerque	2-78				4		2-78	1			3	1
Dugway	1-78				4		1-78				4	
Alaska	10-77				4		10-77				4	
Seattle	1-78				4		1-78				4	
San Nicolas Island	4-78			2	2		4-78				4	
Mines Peak	5-78			4			5-78			4		
Totals		0	0	7	37	0		2	3	5	34	6

[a]Four modules of each type initially deployed at all sites.
[b]Temporarily in storage.
[c]Module incurred heavy physical damage.

Table 4-4. Failure Data by Module Type

Block	Module Type	No. Deployed	No. Failed	Average time in field, months	Average time to fail, months	% of those deployed that failed	% of block failures
I	Sensor Tech	92	9	44	21	9.7	18.7
	Spectrolab	78	4	44	23	5.1	8.3
	Solarex	55	8	44	24	14.5	16.6
	Solar Power	36	27	44	17	75.0	56.2
II	Sensor Tech	110	2	34	36	1.8	16.6
	Spectrolab	70	0	30	-	-	-
	Solarex	79	3	30	22	3.8	25.0
	Solar Power	71	7	31	21.5	9.8	58.3
III	Sensor Tech	24	0	21	-	-	-
	Solarex	12	0	21	-	-	-
	Solar Power	9	0	21	-	-	-
	ARCO Solar	10	0	23	-	-	-
	Motorola	8	0	23	-	-	-

Table 4-5. Failure Data by Site

	JPL	Table Mt.	Goldstone	Pt. Vicente	Canal Zone	Key West	New Orleans	Crane	Houghton	New London	Albuquerque	Dugway	Alaska	Seattle	San Nicolas	Mines Peak	TOTAL
Block I																	
No. deployed	165	49	47														261
No. failed	36	10	2														43
% deployed that failed	22	20	4														
Block II																	
No. deployed	80	18	18	18	16	16	16	16	16	16	16	16	16	16	16[a]		326
No. failed	7	0	0	0	2	1	1	0	0	0	1	0	0	0	0		12
% deployed that failed	8.75	–	–	–	12.5	6.2	6.2	–	–	–	6.2	–	–	–	–		
Block III																	
No. deployed	18	15	15	15													63
No. failed	0	0	0	0													0

[a]All modules stolen.

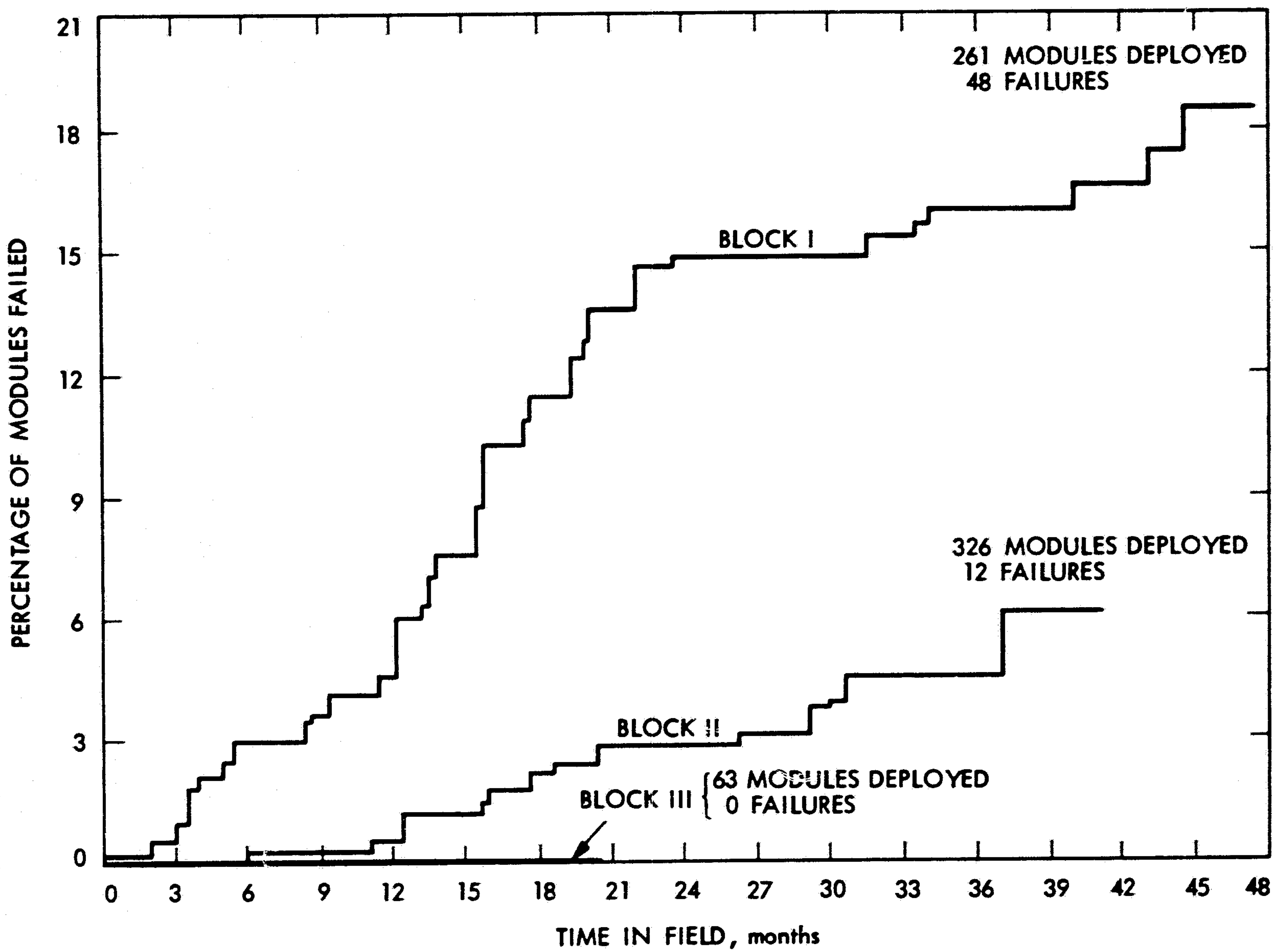

Figure 4-1. Failure Rate Curves for Block I, II and III Modules

B. CAUSES OF FAILURE

When a module fails, a Problem Failure Report (PFR) is written and the module is sent to the LSA Failure Analysis Group. A detailed examination of the module is carried out to determine the cause of the failure. The failure reports were reviewed to determine what the common causes were of field test module failure. The following summarizes the findings:

(1) Virtually all failures were the result of cracked cells or broken interconnects.

(2) Regarding interconnect failures, at least two mechanisms were identified: mechanical fatigue failures resulting from thermal cycling, and failures due to, or accelerated by, a prestress condition that occurred during manufacture, such as a twisted interconnect.

(3) Generally, cracked cells do not lead immediately to failures but lead to reverse bias heating which, in turn, causes the failure. Often, cracks have no effect on performance depending upon the size and location of the crack. Cracks that do not cut the primary collector metallization generally have no effect on performance.

(4) Although many of the failed modules had visual flaws in the encapsulant and other portions of the module, none of the failures were attributed to these flaws.

C. ELECTRICAL DEGRADATION

For the most part, module electrical degradation is a transient condition that exists before a module destined to fail finally fails. Of the modules that failed last year at the JPL site all but one were degraded prior to failure, and that one failed outright with no warning. The others were on the degraded list for one to 18 months before failing. The average time was about four-and-a-half months.

The factors leading to degradation, therefore, are the same as those leading to failure: environmental trauma resulting from hail, rocks, heavy winds, vandals, birds, etc., and material fatigue from temperature cycling, wind load cycling, etc. In the case of a material fatigue failure (such as an interconnect failure) the fatigue is the result of prolonged field exposure. However, until that instant when the fatigue causes the actual rupture, there is no electrical degradation. When the degradation comes, it is abrupt. It is likely that some process is active that will eventually cause slow electrical degradation, i.e., material deterioration due to environmental exposure (UV, high and low temperatures, moisture, salt spray, etc.). But so far, degradation of this type has not been observed.

Quantifying electrical degradation is an almost impossible task. By definition, when the electrical performance of a module is degraded there is a degeneration of the I-V curve. However, a degraded module can have a good I-V

curve in the morning and a degenerated curve in the afternoon, or a good curve on one day and a degenerated one the next. In general, degradation is intermittent and its magnitude is nonrepeatable.

One conspicuous number among the degradation statistics in Table 4-1 is the 19 degraded Sensor Tech II modules at JPL. In almost all of these degradation was due to impact cracks that resulted from hail the year before last. Two interesting things can be noted from the statistic. First, all the Sensor Tech II modules at the site have cracked cells as a result of the hail, but not all of them have degraded. The modules typically have more than one cracked cell, often as many as eight. However, there is no correlation between the number of cracks and whether or not the module has degraded. Second, it took almost a year for the hail impact damage to manifest itself in the form of degraded modules. Interestingly, there are two degraded Sensor Tech II modules at Houghton, Michigan with the same impact crack symptoms. Last year these modules were functioning normally. A review of the weather data indicated that the last time they were subjected to hail was the year before last.

D. PHYSICAL INSPECTION DATA

The most difficult and subjective part of endurance testing is quantifying the physical condition of modules. The method currently being used is the result of two years of evolution. In the past, each module, regardless of design, was inspected with the same all-encompassing set of inspection categories. This approach was not successful, as it did not focus the inspection on the critical areas or correlate specific problems with specific designs. The current method takes advantage of composite observations from all sites to provide a list of common defects for each design. This list is then used to compare the modules on a site-by-site basis. The prevalent defect list alone is important because it indicates what the problems are for each module design. The comparisons show how the different environments affect the common problems. Table 4-6 presents a list of the common defects for the Block I, II and III modules. This list was generated with the assistance of the LSA Quality Assurance Group.

A comparison showing how the modules hold up in the different environments is presented in Table 4-7. This table contains the inspection data of all the Block II modules at all 16 sites. This data was used for comparison because the Block II modules are the only ones universally deployed. The "Probable Effect" column of the table is an estimate of the importance of each defect relative to the actual function of the module. Some conclusions that can be reached from the physical inspection data are:

(1) Most common physical defects, with the exception of cracked cells, do not result in serious performance problems.

(2) There does not appear to be any correlation between the physical condition of a module and its electrical performance. Often, modules display severe physical degradation but function well.

Table 4-6. Common Physical Defects for Block I, II, and III Modules

BLOCK I	
PHYSICAL DEFECT	COMMENT
<u>Sensor Tech</u>	
Interconnect breakthrough	Occurs at the solder joint between the mesh interconnect and the output terminal wire.
Output terminal hardware corrosion	Severe corrosion of output terminal screw heads found on early production modules; problem corrected with stainless steel screws.
Internal output wire corrosion	Bell-shaped whitish discoloration observed in encapsulant along insulation on output terminal wires.
Encapsulant repair failures	Usually occurs over replaced cell, but also where encapsulant has been poured over an interconnect breakthrough.
Delamination at output terminal	Delamination occurs at output terminal between centerpost and frame.
Embedded dirt	The "primary" or embedded dirt is the dirt that cannot be washed off by a normal detergent washing. Its presence cuts the transmittance through the encapsulant and decreases the output power.
<u>Spectrolab</u>	
Cracks in output terminal posts	Usually radial cracks; problem more prevalent on red (positive) post.
Air bubble migration in encapsulant	Air bubbles continually develop in these modules, probably from air entrapped under cells. Bubbles move about freely and sometimes disappear.
<u>Solarex</u>	
Frame seal delamination	Extensive delaminaton observed around whole perimeter of many modules. In most cases delamination has spread inward to the cells.
Cracked cells	Impact type cracks, probably due to hail.
Embedded dirt	
<u>Solar Power</u>	
Frame seal delamination	Extensive delamination observed around whole perimeter of many modules. In most cases delamination has spread inward to the cells.
Interconnect/cell delamination	Delamination between cells and under interconnect almost universal.
Hard-coat splitting	Splitting in surface hard-coat widespread.
Deterioration of junction boxes	Junction box sidewalls tend to fall off.
Deterioration of output wire insulation	Cracks and general deterioration of the insulation universal.
Embedded dirt	

Table 4-6. Common Physical Defects for Block I, II, and III Modules (Cont'd)

BLOCK II	
PHYSICAL DEFECT	**COMMENT**
Sensor Tech	
Cracked cells	Usually impact type cracks, possibly from hail. This design has a propensity for developing cracked cells.
Ground terminal corrosion	The steel grounding screw, nuts and star washers at many sites have corroded, particularly near the ocean.
Protective terminal boot deterioration	The rubber boots lose their elasticity and eventually split.
Growths developing in encapsulant	Greyish growths developing between fiberglass screen and substrate. With time the growths merge and form raised areas.
Embedded dirt	
Solarex	
Cell grid and collector discoloration	Universal problem. Discoloration starts yellow and eventually becomes a rust color. Analysis indicates that the process is probably self-terminating with no adverse consequences.
Module frame corrosion	Some corrosion noted on the anodized aluminum frame.
J-box and output connector corrosion	Common outdoor electric box. At some sites substantial corrosion observed.
Embedded dirt	
Solar Power	
Cracked cells	Some cracked cells seen, but not a significant amount.
Frame seal/substrate delamination	Universal problem. Often massive delamination occurs around whole perimeter. In some cases encapsulant has peeled away from substrate. Dirt and water often get entrapped between encapsulant and substrate.
Interconnect/cell surface corrosion	A whitish and occasionally greenish corrosion develops at or near the interconnect solder joints on the cell metallization and the interconnect.
Hard-coat crazing	Seems to occur more often in dry or cold environments.
Substrate deterioration	A surface breakdown of the exposed polyester fiberglass substrate material observed. Needles of fiberglass now at surface.
Embedded dirt	
Spectrolab	
Terminal strip/solder joint discoloration	Discoloration of the terminal strip attached and adjacent to the seals going to the output plugs has occurred at most sites.
Rubber output connector deterioration	Automobile-type rubber connectors used; they tend to crack and check, particularly in dry environments.
Frame screw fastener corrosion	Steel cadmium-plated phillips screws and star washers have corroded in many environments, particularly near the ocean.
Module frame corrosion	Light corrosion of the aluminum frame is common.

Table 4-6. Common Physical Defects for Block I, II, and III Modules (Cont'd)

BLOCK III	
PHYSICAL DEFECT	COMMENT
<u>Sensor Tech</u>	
Cracked cells	Impact-type cracks.
Protective terminal boot deterioration	Splits very common.
Delamination at output terminal	
Embedded dirt	
<u>Solarex</u>	
Same as Solarex, Block II	
<u>Solar Power</u>	
Same as Solar Power, Block II	
<u>ARCO</u>	
Corrosion of output terminals	A heavy coat of corrosion has formed on all output terminals of these modules.
Substrate edge discoloration	A yellow to rust color band of discoloration has appeared along the sides of a number of these modules. The bands are continuing to become longer, darker and wider.
Cell collector discoloration	Occasionally a cells' metalization will turn a deep rust color. The adjacent cells usually look normal.
<u>Motorola</u>	
Ruptured internal corner seals	Extrusion of gel material through ruptured corner seal common.
Gel material discoloration	A cloudy whitish discoloration band has formed in the gel material near the frame on many modules. The discoloration is greatest at the interconnect sheet cut-outs and appears to be oriented with them.
Interconnect sheet discoloration	Dark purple discoloration develops along cut-outs of the gold interconnect sheet; usually associated with gel material discoloration.
Gel material leakage	Gel material seeps out from the edge of metal frame and leaks over the cover glass.
Discoloration of metalization	Grid and collector lines on outer peripheral cells turn black.

Table 4-7. Physical Inspection Summary of Block II Modules

	COMMON PHYSICAL DEFECTS	PROBABLE EFFECT	JPL	TABLE MT.	GOLDSTONE	PT. VICENTE	CANAL ZONE	KEY WEST	NEW ORLEANS	CRANE	HOUGHTON	NEW LONDON	ALBUQUERQUE	DUGWAY	ALASKA	SEATTLE	SAN NICHOLAS
SENSOR TECH	CRACKED CELLS	a	●	O						O	◑	O				O	
	GROWTHS DEVELOPING IN ENCAPSULANT	u	◑	O									O				
	GROUND TERMINAL CORROSION	u				◑	◑	●	◑	●		O	O			◑	O
	PROTECTIVE TERMINAL BOOT DETERIORATION	d			◑	O				O		O	O	O			
	OUTPUT TERMINAL HARDWARE CORROSION	d		O		O				O							◑
	EMBEDDED DIRT	b	◑	O	O	◑	O	O	◑	O	O	O	O		O	O	O
SOLAREX	CELL GRID AND COLLECTOR DISCOLORATION	d	◑	O	◑	◑	◑	O	◑	O	O	O	O	O	O	O	O
	MODULE FRAME CORROSION	c	O			O	O	O	O			O				O	O
	J-BOX AND OUTPUT CONNECTOR CORROSION	c				◑	O	●	◑			O		O			◑
	EMBEDDED DIRT	b	O	O	◑	O	O	O	◑	O	O	O	O		O	O	O
SOLAR POWER	CRACKED CELLS	a	O				O		O		O				O	O	
	FRAME SEAL/SUBSTRATE DELAMINATION	a	◑	◑	◑	◑	◑	◑	◑	O	O	O	●	●		O	O
	INTERCONNECT/CELL SURFACE CORROSION	u	◑	O	O	O	O		O				O	◑	O	O	
	OUTPUT INTERCONNECT/SOLDER JOINT CORROSION	u	O	O		O	◑	◑		◑		O	O	O	O	◑	O
	HARD-COAT CRAZING	c		◑	O					O	◑		O	O	O		O
	INTERCONNECT BREAKTHROUGH	u				O										O	
	SUBSTRATE DETERIORATION	c	O	O	O	O	O	◑	O	O	O		◑	O		O	
	EMBEDDED DIRT	b	O	O		O	O	O	◑	O		O				O	O
SPECTROLAB	TERMINAL STRIP/SOLDER JOINT DISCOLORATION	d	O	O	◑	◑	O	◑	O	O	O	O				O	O
	RUBBER OUTPUT CONNECTOR DETERIORATION	u	◑	◑	◑					O	O	O	O	◑	O		
	FRAME SCREW FASTENER CORROSION	c				◑	◑	●	O	O		O				◑	
	MODULE FRAME CORROSION	c	O			O	O	O	O	O		O		O		O	O

PROBABLE EFFECTS

a POTENTIAL ELECTRICAL FAILURE

b RESULTS IN POWER DECREMENT

c PRIMARILY COSMETIC

d LIKELY NOT SERIOUS

u UNKNOWN

SEVERITY SCALE

NONE

SOME

O MODERATE AMOUNT

◑ SIGNIFICANT AMOUNT

● EXTREME CONDITION

(3) Hot, humid environments appear to be the most damaging; cold, dry environments the most benign. Smoggy environments rank near hot, humid environments in severity of damaging effects.

(4) The following should be avoided in module design:

- Dissimilar metal components in contact with one another.

- Neoprene electrical connectors and protective devices.

- Galvanized materials for near-ocean applications.

- Module structures that retain water between the lower frame and the encapsulant.

(5) Module deficiencies appear to be either design-related or a result of poor fabrication practices. For instance, delamination is generally the result of poor substrate preparation prior to encapsulant application, or the result of a design that does not satisfactorily anchor in the encapsulant.

(6) Two highly successful design features are:

- Wrap-around frame encapsulant containment design of Solarex II modules.

- The PVB-laminated construction of Spectrolab II modules.

(7) Glass modules have superior non-soiling and self-cleaning characteristics.

SECTION V

FUTURE PLANS

Two major changes are planned for next year: (1) a significant site expansion program will be undertaken in preparation for the Block IV module deployment, and (2) the operating emphasis at the JPL site will shift away from daily data acquisition and toward support experimentation.

A. SITE EXPANSION AND BLOCK IV DEPLOYMENT

It is anticipated that contracts for the procurement of Block IV modules will be issued in the fall and winter of 1980-81 and that the modules will arrive in the spring and summer of 1981. To accommodate the Block IV modules, additional test space will be required, particularly at the Continental Remote sites. The plan for reorganization is as follows: Eight of the Continental Remote sites will be enlarged in capacity to about twice their current size. These include the Canal Zone, Key West, New Orleans, Houghton, New London, Albuquerque, Fort Greely (Alaska) and Mines Peak sites. Most of the modules currently deployed at these sites will be removed and replaced with Block IV modules. A small quantity of Spectrolab and Solarex modules will remain to provide testing continuity for the two encapsulant materials currently in use (glass and silicone rubber). The Seattle and Crane sites will not be enlarged; Block IV modules will be deployed at these sites but in smaller quantities than at the above sites. No Block IV modules will be deployed at either Dugway or San Nicholas, but the Block II modules currently there will remain.

The rationale behind the plan is as follows: (1) there will not be enough Block IV modules to satisfactorily stock all 12 Continental Remote sites and (2) some of these sites are not critical; they provide either redundant or nonstressful environments. The San Nicholas Island environment is duplicated at Point Vicente, and the Dugway environment is duplicated at Goldstone and Albuquerque. Seattle and Crane are fairly benign environments but, as they represent large geographic areas, a smaller Block IV test sample will be used.

Changes are also planned for the Southern California sites. Most of the Block I modules will be removed, as they have outlived their usefulness. A significant portion of the Block II modules will also be removed, particularly at the remote sites.

B. EXPERIMENTATION EMPHASIS SHIFT AT THE JPL SITE

A shift in emphasis toward using the JPL test site as an experimental facility is planned. There is a growing need to perform in-depth investigations of problems observed in the field. Unique capabilities offered

at the JPL site that provide an excellent opportunity for conducting these investigations are:

(1) The data system, with its versatility and extensive computer and storage capability, can tie into and collect data from modules, thermocouples, weather instruments, pyranometers and other instruments, as required.

(2) A flexible arrangement exists for wiring into the data system.

(3) The test stands can be tilted and linked together, as required, for mounting both large and small test samples.

(4) A LAPSS system is available for substantiating and complementing data obtained from the field experiments.

(5) Experts from every facet of photovoltaics within the LSA Project are available for consultation.

(6) All manner of support is available at the Laboratory: electronics, wiring, machine shop, etc.

(7) A network of test sites exists under the control of the Field Test Group, providing a broad range of environments for special tests.